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Remote Sensing Applications in Archaeological Research

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1. Introduction

The spectral capability of early satellite sensors opened new perspectives in the field of archaeological research. The recent availability of hyperspectral and multispectral satellite imageries has established a valid and low cost alternative to aerial imagery in the field of archaeological remote sensing. The high spatial resolution and spectral capability can make the VHR satellite images a valuable data source for archaeological investigation, ranging from synoptic views to small details. Since the beginning of the 20th century, aerial photography has been used in archaeology primarily to view features on the earth's surface, which are difficult if not impossible to visualize from the ground level (Rowland and Sarris, 2006 ; Vermeulen, F. and Verhoeven, G., 2004). Archaeology is a recent application area of satellite remote sensing and features such as ancient settlements can be detected with remote sensing procedures, provided that the spatial resolution of the sensor is adequate enough to detect the features (Menze et al., 2006). A number of different satellite sensors have been employed in a variety of archaeological applications to the mapping of subsurface remains and the management and protection of archaeological sites (Liu et al., 2003). The advantage of satellite imagery over aerial photography is the greater spectral range, due to the capabilities of the various on-board sensors.

Most satellite multi-spectral sensors have the ability to capture data within the visible and non-visible spectrum, encompassing a portion of the ultraviolet region, the visible, and the IR region, enabling a more comprehensive analysis (Paulidis, L., 2005). Multispectral imagery such as Landsat or ASTER is considered to be a standard means for the classification of ground cover and soil types (Fowler M.J.F., 2002). Concerning the detection of settlement mounds the above sensors have been proved to be helpful for the identification of un-vegetated and eroded sites. In recent years the high spatial resolution imageries of IKONOS and Quickbird have been used for the detection of settlements and shallow depth monuments (De Laet et al., 2007; 36 Massini et al., 2007; Sarris, A., 2005). Hyperspectral imagery (both airborne and satellite) has been also applied in archaeological investigations on an experimental basis and need further investigation (Cavalli et al., 2008; Merola et al., 2006).

The record of electromagnetic radiation can be achieved using special sensors. Such kind of sensors are used to record the electromagnetic radiation from satellites while handheld sensors can be used for field measurements. The ground radiometry and spectroscopy involves the study of the spectral characteristics of objects according to their physical properties (Milton, 1987). Indeed, data from portable radiometer are often refer in the literature as "ground truth data", due to the fact that measurements are collected in a relatively short distance from the object so that any noise is minimized (Jonhson, 2006). However, as Curran and Williamson (1986) emphasizes even these ground "true" data are subject to errors, which researchers should take into account.

The spectral signature diagram, from different materials or objects, is an easy way to plot radiation against wavelength, in a graphical form. Curves of spectral signature (reflectance curves) and the so-called critical spectral bands (critical spectral regions) are used in many applications of Remote Sensing (e.g. vegetation indices). The way of how measurements are collected by radiometers can be explained through physical laws. Already, by the 1970s Nicodemous et al. (1977) have proposed the basis for the model of "bidirectional reflectance distribution function" (BRDF), which describes the relationship of the incident radiation from a given address in the reflected radiation in another direction. Nevertheless, the use of the results of the Nicodemous et al. (1977) study was not appreciated and understood by the scientific community (Schaepman-Strub et al., 2006; Milton et al., 2009). Their study has been used several years later by Martonchik et al. (2000) and Schaepman-Strub et al. (2006). The original classification proposed by Nicodemous et al. (1977), depending on the geometry of the radiation which included nine categories was reduced to only four which are actually encountered (Martonchik et al., 2000; Milton et al., 2009).

Milton et al. (2009) stated that all spectroscopy measurements in a strict physical sense can be categorized within the "hemispherical-conical reflectance function" (HCRF case). It should also be noted that natural materials do not follow the rules of a diffuse Lambertian surface, since the intensity of the reflected radiation varies regarding the angle of refraction.

Ground spectroradiometer may be used to provide calibrated measurements, since these instruments are often accompanied by special Lambertian targets. Milton et al. (2009) emphasizes that a critical factor for good results is the calibration of a specific target. The only disadvantage, apart from the price of handheld spectroradiometer is that it is difficult to cover a large area (such as an archaeological site) (Atkinson et al. 1992; Milton et al., 2009).

Apart from the purchase of the ground radiometry, there is still an important limitation that should be taken into account. Most spectroradiometers which are found in the market are "single-beam": the same instrument used to measure the radiation to a specific target (reference panel) used to measure the targets of interest (target). In the interval of these measurements the atmospheric conditions are assumed to be the same.

Spectroradiometer may be used for archaeological research in order to retrieve characteristics of vegetation and to calculate vegetation indices. Such indices are quantitative measures, based on vegetation spectral properties that attempt to measure biomass or vegetative vigor. Theoretical analyses and field studies have shown that VIs are near-linearly related to photosynthetically active radiation absorbed by plant canopy, and therefore to light-dependent physiological processes, such as photosynthesis, occurring in the upper canopy (Glenn et al. 2008).

Concerning geophysical techniques they offer a non-invasive way of providing valuable information regarding the subsurface context of the archaeological sites and contribute significantly in leading archaeological excavations, reconstructing the past landscapes, suggesting directives for the cultural heritage management and preservation of sites and historical buildings and providing a prior strategy for large construction works. Employing a suite of methods measuring the physical properties of the soils with high efficiency, reliability and resolution, geophysical prospection has been designated as a valuable tool in the domain of archaeological research, especially in the study of the ancient landscapes. A very detailed review of the physical properties of each method and the fundamentals of the operation of the corresponding instrumentation is provided by Linford (2006) and Scollar et al. (1990).

Methods that involved measurements of the soil's electrical resistance and of the local intensity of the magnetic field of the earth have been the earliest that were applied in the field of archaeological prospection. Making use of Ohm's law, soil resistance meters, acting as active prospection methods, introduce a current within the ground through the use of metal electrodes and measure the electrical resistance of the soil, as this is influenced by the features located within the ground and below the electrode array (Clark, 1990). Soil resistance measurements can be carried out in two main ways, either by moving a fixed electrode spacing (corresponding to a specific penetration depth) array along profiles or through vertical electrical soundings (VES) (Sarris, 2008). In the latter, the current electrode spacing is increased with respect to a fixed centre of the electrode array, providing plots of the apparent resistivity versus electrode spacing that are ultimately compared to theoretical curves to provide information about the layering of the subsoil's strata. Soil resistance values are modified depending of the resistivity contrast of the targets (eg. a high resistance wall structure or a high conductive ditch) with the surrounding soil matrix. The measured apparent resistivity is also affected by the type of the configuration of electrodes (e.g. Twin probe, Square, Wenner, pole-pole, dipole-pole) and the distance between the electrodes, which is relatively proportional to the penetration depth.

This chapter seeks to address applications of remote sensing and GIS in archaeological research in a three-fold way. Initially, potential of satellite remote sensing is highlighted through a multi – sensor case study in Thessaly, Greece, where different satellite image processing techniques contributed to the detection of Neolithic tells (the so called 'magoules') that are found in the Thessaly plain. Four satellite remote sensing images with different spatial resolutions (ASTER, Landsat, HYPERION, IKONOS) were examined in order to search their potential for automatic extraction of Neolithic settlements, by means of pixel – based (RGB composites, spatial and radiometric enhancement, vegetation indices, data fusion, classification methods, data fusion etc). The satellite data were statistically analyzed, together with other environmental parameters, to examine any kind of correlation between environmental, archaeological and satellite data. Moreover, different methods were compared and integrated methodologies for the detection of Neolithic settlements were extracted.

Concerning ground spectroradiometer contribution to archaeological research, new innovative tools and methodologies are also presented in this chapter. Specifically, ground "truth" data, presented as spectral signatures libraries, were provided from different

spectro-radiometric campaigns at archaeological environments (e.g. Tombs of the Kings and Sikyon archaeological site, C. Greece). Moreover field spectroscopy was used to detect buried archaeological sites in similar ways as applied in remote sensing applications in Neolithic tells in Thessaly. In addition the comparison of the phenological cycle 5 profile of similar crops - under same meteorological and soil conditions - is also searched over archaeological and non archaeological sites concerning for different case studies in Cyprus.

At the end, in order to highlight the potential of geophysical remote sensing in archaeological research certain case studies from surveys held in Greece and Europe are presented such as magnetic surveys in the Neolithic settlement of Veszto -Bikeri in Hungary and the Byzantine walls of ancient Nicopolis in Greece, the ground penetrating radar methods in the ancient Agora of Feres (Velestino) in Thessaly, in Agora of Sikyon at NE Peloponesse - Greece and in the area of the hypothesized amphitheatre of Ierapetra (SE Crete and finally the electrical resistivity tomographies from the Nemea, Peloponesse.

2. Application of remote sensing, GIS and geomorphology to the reconstruction of habitation in Neolithic Thessaly

2.1 Introduction

The aim of this study is to highlight the contribution of different approaches such as Remote Sensing, GIS and geomorphology analysis for the detection of Neolithic settlements and the modeling of habitation in the area of Thessaly - Greece.

The Neolithic settlement mud mounds in the area of Thessaly, Greece are called Magoules. They are low hills of 1-5 meters height and mean diameter 300 meters. The vast majority of Magoules are laid on Larisa basin and a smaller number is distributed in west Thessaly (Karditsa basin) (Fig.1). Both of these plains consist of Quaternary alluvial deposits (Alexakis et al. 2008). In order to achieve the goals of the research it was necessary to proceed with the topographic mapping of the settlements through the use of GPS, digitize 1:50,000 scale topographic and geological maps and construct a detailed archaeological and environmental database in SQL environment.

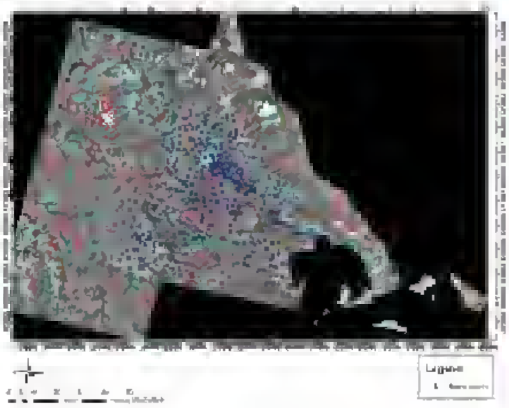


Fig. 1. Color composite RGB→3,2,1 of the mosaic of the 4 ASTER images used to cover the whole area of interest. The dots represent the location of the Neolithic magoules (left). Magoula Aerino (right).

2.2 Landscape reconstruction

Prior to the landscape reconstruction of Thessaly during different Neolithic periods, the reliability of the existing Digital Elevation Model (DEM) was evaluated compared to other digital elevation models, such as the 90m pixel size DEM (from the Shuttle Radar Topography Mission (SRTM) and the 30m pixel size DEMs provided by ASTER images or constructed by the L1-A stereoscopic products (3N and 3B) of ASTER. The results indicated that the RMSE for the DEM created through the digitization of the contour lines of the topographic maps was the lowest. The two major plains of Thessaly contain 181 out of the 342 known registered "magoules", stressing the important role of reconstruction of the relief of each basin during each Neolithic sub-period. Both geological (stratigraphic data from boreholes and past geomorphologic studies) and archaeological data were placed under consideration for achieving this task and a reconstructed DEM for each basin and each Neolithic period was created.

2.3 Satellite image processing

2.3.1 Data and preprocessing of satellite images

Concerning this study different multispectral images were used. Specifically, 4 IKONOS images of 1m pixel size, 1 Landsat ETM+ 30m pixel size image, one 30 m pixel size Hyperion image and 4 ASTER images (15, 30 and 90m pixel size). Masking of the sea, clouds and snow areas in all images preceded the processing of the images in order to focus to the mainland and the areas that provided useful information. Image mosaics were created accordingly depending on the types of sensors and both image mosaics and isolated images were rectified to a common projection system (EGSA87/HGSR87). Digital numbers of images were also converted to reflectance values according to specific conversion equations. The last step was necessary in order to have a uniformity in the values of images originating from different sensors.

2.3.2 Spectral enhancement techniques

Several RGB composites were constructed in an effort to examine their efficiency in the detection of the Neolithic settlements. For the ASTER image with acquisition date 19-03-2003, where most of the magoules were registered, the RGB→1,2,3, RGB→3,2,5 and RGB→2,3,7 composites were the most successful for the visual detection of the Neolithic settlements (39 out of 239 settlements were highly visible, 49 average visible and 151 poorly visible). All these composites appeared to have the highest Optimum Index Factor (Alexakis et al, 2009). Similarly, RGB composites of IKONOS images were able to detect 27 out of 48 settlements within their area of coverage. It is worth mentioning that 19 of the detectable magoules, namely the highest of all corresponding to an average altitude of 4.6m, were highly visible in all RGB composites. On the other hand, RGB composites of Landsat and HYPERION images were not very promising (for HYPERION composites only 5 out of 21 settlements were detected). Due to their high spatial resolution, all the 5 settlements that felt within the spatial limits of the aerial photo mosaic were easily detectable. As a general conclusion however, the acquisition date of the images proved to be the most crucial factor for the detection of magoules mainly due to the intensive cultivation (mainly soft and shallow cultivation) of the landscape both on the top and the surroundings of magoules. Principal Component Analysis (PCA) was applied to ASTER, Landsat and Hyperion

images, being especially effective for ASTER images where 39 and 47 out of 247 settlements were highly or medium discriminated correspondingly. Image fusion techniques through the combination of high spatial resolution images such as IKONOS (1m) and high spectral resolution images such as Hyperion (30m) concluded to very promising results (Fig 2). Finally, a spectral mixer utility (Erdas Imagine 9.1 software) contributed to exploit the dynamic range of all the multispectral information of the Hyperion image by combining more than three bands to an RGB composite. Using the specific utility and assigning a weighting coefficient for each band, a RGB composite of 23 bands (38, 42, 48, 49, 50, 51, 52), (85, 86, 87, 88, 89, 90, 91, 92,) & (93, 94, 108, 109, 110, 111, 113, 114) was constructed that enhanced the visual appearance of the magoules.

2.3.3 Spectral enhancement techniques

Radiometric enhancement was vital for the appearance of the images. After applying radiometric enhancement to ASTER images (acquisition date of 19-03-2003) we managed to detect 57 settlements (Fig. 2). A non-linear radiometric enhancement of the HYPERION PCA image, followed by an inversion of brightness was able to highlight 8 settlements from a total of 9. (Melia 1, Melia 2, Anagennisi 2, Moshohori 3, Kipseli 2, Prodromos 1 of Larisa, Nikaia 17 and Kuparissia 2). Similar type of non-linear radiometric enhancement of the high resolution IKONOS images through the modification of the histogram outlined the round shape of known magoules, as well as outlined 10 more targets of similar geometry that need to be verified by the ground truthing activities that will follow (Fig. 2).

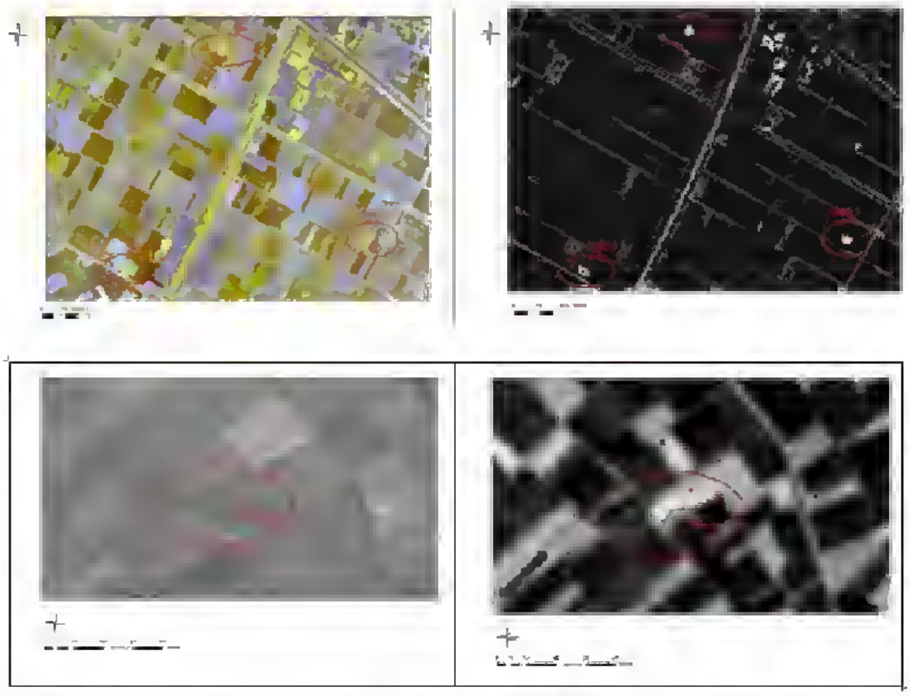


Fig. 2. Appearance of 3 settlements in the original IKONOS image (left) and the radiometrically enhanced image where three Neolithic settlements are highlighted (right). To the north of Galini-3 settlement, shown at the lower right of the image), another smaller potential magoula is suggested.

2.3.4 Land classification, vegetation indices, spatial enhancement

A spectral signature database was constructed to provide the basic spectral information about tells, especially at the plain areas of Thessaly. Several classification methods were applied to Landsat and ASTER images in order to investigate the land use regime around the magoules. Examination of the overall accuracy of the various algorithms tested (based on the error matrix), proved that the Mahalanobis algorithm was the most efficient for the exact classification of the images (Fig. 3a). Additionally, object based segmentation techniques were applied to ASTER images and 15 settlements in total of 234 were detected easily (Alexakis, 2009). The computation of the Normalized Difference Vegetation Index (NDVI) was used to highlight the vegetation differences during different periods of time, in an effort to pinpoint any vague indications for the detection of magoules. As expected, the NDVI of the "spring" ASTER image was higher than the "summer" Landsat image, but still the vegetation differences of the spring time favored the detection of magoules mainly due to the differentiations in the soil's humidity (Fig. 3b).

Application of certain spatial high pass filters contributed further to the spatial enhancement of smaller features such as the magoules. The most reliable of them proved to be Sobel Right Diagonal 3x3 and Laplace 3x3, both of which outlined clearly the limits of the most prominent of them (Fig. 3c).

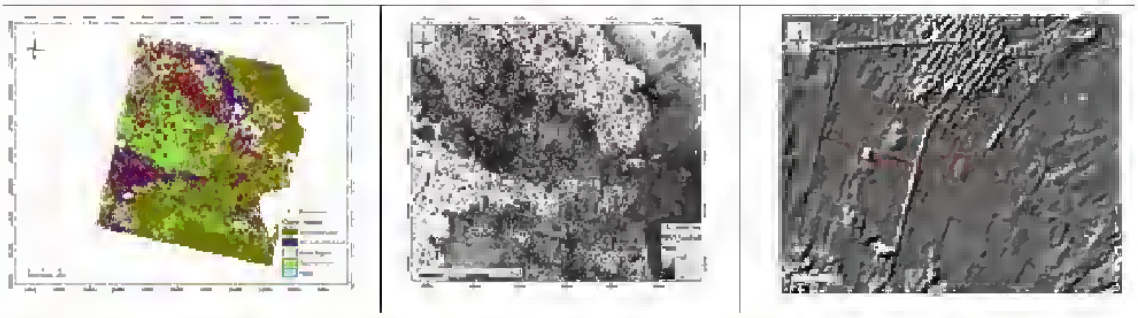


Fig. 3. (a) Land classification of ASTER image through the use of Mahalanobis distance (fuzzy) algorithm. (b) Detail from the application of NDVI to ASTER image. (c) ASTER image around Halki area after the application of Sobel Right Diagonal filter. Neolithic magoules are indicated within the ellipses.

2.4 Analysis in GIS environment

An extensive spatial analysis of the magoules distribution was carried out in GIS environment using the reconstructed DEMs. Besides the extraction of statistics regarding the relation of settlements to the aspect, slope and relief height, the distance of settlements from natural resources was calculated by applying buffer zones around the quarries and the water springs (mainly springs existing on the mountainous areas). Watersheds were constructed and the distance of each settlement from its neighbor watershed was calculated. Density maps of the settlements were created for each Neolithic period. The calculation of the density of the settlements was accomplished through the use of a non-parametric Kernel technique. The spatial territorial limits of the settlements were explored using the Thiessen polygons analysis. The site catchment of Neolithic settlements was studied through least cost surface analysis. Cost surfaces contributed also to the exploration of communication routes between the different settlements (Alexakis, 2011).

Finally, GIS tools were employed to construct predictive habitation models for each phase of the Neolithic period in an effort to locate areas that could possibly host similar type of settlements. The specific predictive models were based on the use of a multi-parametric spatial analysis method of geographic elements and other information (statistical, archaeological, a.o.). All the environmental factors (height, aspect, slope, distance from watersheds, distance from water springs, distance from quarries, geology, viewshed, distance from chert sources, least cost paths, a.o.) that could affected the choice of habitation in Neolithic Thessaly were statistically examined and certain weight factors were applied to each one of them. At a final stage, a fuzzy logic algorithm and a normalization equation were also applied a more efficient tuning of the results and for rating the final probability from 0 to 1.

2.5 Application of sophisticated fields to the Digital Elevation Models

The final approach of the particular project involved the detection of Neolithic settlements through the analysis of DEMs with the use of three different semi-automated methodologies. Three different DEMs (90m pixel size SRTM DEM, 30m ASTER DEM and a 20m DEM from the digitization of contours of topographic maps) were tested in all procedures to attest for their potential in the detection of the magoules.

The first methodology involved the estimation of the index of convexity (CI) to the three different DEMs according to Fry *et al.* (2004):

$$CI = (x - x_{med}) / (x_{max} - x_{med}), \tag{1}$$

where x is the initial DEM, x_{med} is the DEM after the application of median 7x7 filter and x_{max} is the DEM after the application of maximum 7x7 filter.

Although the index of convexity seemed to be ideal for the detection of low hills such as magoules, only 35 (28%) of them at Larisa plain and 28 (47%) at Karditsa plain were detected by this method.

The second methodology is related with the design and application of customized filters similar to those used by Menze and Sherratt (2006). The optimal filter for the detection of a signal with a well known shape is the matched filter (Fig. 4). For the construction of the matched filter, an area of 5x5 pixel was cut around the DEM of each settlement for a total of 50 settlements. Then, the value of the central pixel was subtracted by each pixel, followed by stacking of all the 50 local DEMs (through the layer stack utility of Erdas Imagine software) to form a final multilayer image. The particular image was imposed to Principal Component Analysis and the first 5 principal components were summed. The negative sum replaced the value of the central pixel of each of the above 5 filters, which they were then applied individually to Larisa and Karditsa basins as a detection filter (Fig. 14). The statistics for these filters proved that the specific methodology is really promising especially for the SRTM DEM in the area of Larisa. More specifically, about 60% of the settlements were detected through the application of the first and second filters.

The third methodology followed the approach of Iwahashi and Kamiya (1995) for the estimation of the geometric signatures of DEM through a combined study of slope gradient, surface convexity and texture (Fig. 4). Specifically, binary files were formed through estimation of the mean value of slope gradient: all pixels with value above the mean value

took a value 1 and all the rest took a value of 0. The same binary archives were created after the subtraction of the initial DEM from the one that has been processed through the application of a median filter. The last binary image was created after the application of a Laplace 3x3 filter to the initial DEM. In the end, the three binary archives were summed and the final map highlighted the areas of high local convexity. Fuzzy logic algorithms were applied to the final results of the filtered DEM in order to produce a better classification scheme (Pixel values equal to 0 formed the first group, values from 0 to 3 formed the second group and pixels with value equal to 3 formed the third group) (Fig. 15). The application of this methodology to SRTM resulted to the detection of 35% of the magoules in Larisa plain and only 15% of the magoules in Karditsa plain.

The results obtained through the Menze & Sherratt (2006) approach to the SRTM DEM were also implemented to the predictive modelling, together with other subproducts of the satellite image analysis, such as the NDVI map, land use classification and spectral signatures library of magoules. A similar methodology of significant weights and factors was considered and results were subjected to fuzzy logic and normalization techniques. Still, the results of predictive modelling did not alter significantly from the previous approach, signifying a state of saturation for the parameters considered.

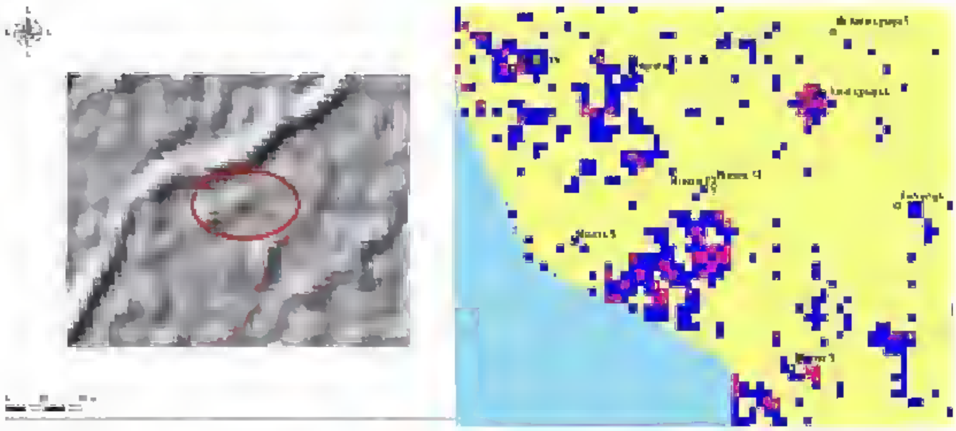


Fig. 4. Magoula Turnavos 6 after the application of matched filter (left). Application of geometric signatures methodology to SRTM DEM in the area of Larisa. With the red color are indicated the areas of higher height where magoules could be established (right).

3. Application of field spectroscopy and satellite remote sensing to archaeology

3.1 Introduction

This chapter aims to introduce the capabilities and the potentials of field spectroscopy to archaeological research (Fig. 5). Field spectroscopy involves not only the acquisition of accurate measurements (e.g. spectral signatures profiles) but also the study of the interrelationships between the spectral characteristics of objects and their biophysical attributes in their field environment. Therefore, field spectroscopy can provide valuable information for an area if we consider the fact that human eye senses only a small part of the electromagnetic spectrum, from approximately 0.4 to 0.7 nm, whereas field spectroscopy in

support of remote sensing operates in a wider spectrum range including near infrared as well. In this section, ground "truth" data, presented as spectral signatures libraries, are provided from different spectroradiometric campaigns at archaeological environments (e.g. Tombs of the Kings and Nea Paphos at SW Cyprus, Sikyon archaeological site, C. Greece). Furthermore, spectral libraries include vegetation profiles, mainly over barley crops (from the Palaepaphos – Cyprus archaeological site and from Neolithic tells at Thessaly - Greece). Such libraries are used in order to examine either the seasonal changes of vegetation, or the anomalies of vegetation profiles due to buried archaeological remains. Moreover, spectral libraries are used for the atmospheric correction of satellite imagery. Finally, the theoretical background of scaling up ground narrow bands taken from handheld spectroradiometers to bandwidths satellite imagery, using the Relative Response Filters, is presented.

Ground spectroscopy may be used as a fast detection method in order to evaluate positive or negative crop marks. In this case sections over archaeological areas are taken and evaluated in terms of vegetation indices. Different Neolithic sites at Thessaly (central Greece) are examined with the use of this approach. Finally, an alternative method for the detection of archaeological remains is presented in this chapter. This method is based on the comparison of the phenological cycle profile of similar crops -under same meteorological and soil conditions -over archaeological and non archaeological sites. The case of Palaepaphos site in Cyprus is presented with the use of medium resolution images (Landsat TM/ETM+) and the support of ground spectroradiometric measurements.

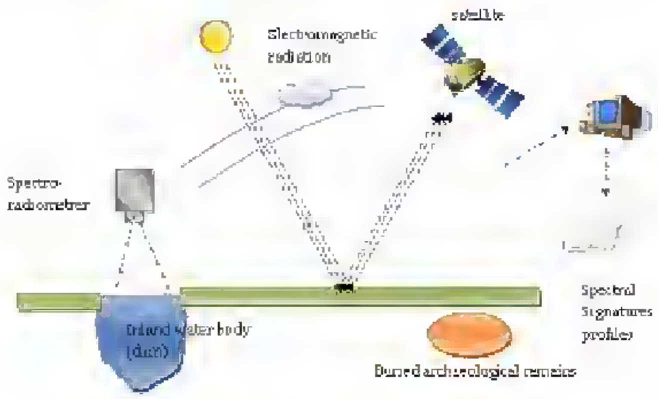


Fig. 5. Potentials of ground field spectroscopy for archaeological purposes

3.2 Collection of field measurements

Field measurements were carried out in different archaeological areas in Cyprus and Greece. The areas investigated and presented in this chapter were fully vegetated with crops. Moreover ground spectroradiometric measurements were taken: a) over visible monuments in order to develop an archaeological spectral signature database and b) at dams (inland clear water) for applying atmospheric correction to satellite images.

The spectroradiometric instrument that was used to register the spectral signature was GER 1500 (Fig. 6). This instrument may record electromagnetic radiation from a range of 350 nm up to 1050 nm. It includes more than 500 different channels and each channel cover a range of about 1.5 nm. The field of view (FOV) of the instrument was set to 4° (≈ 0,02 m^2).

Fig. 6. GER 1500 used in this study with its calibration target (Agapiou et al. 2010)

A reference spectralon panel was used to measure the incoming solar radiation. The Labertian spectralon panel (≈100% reflectance) measurement was used as references while the measurement over vegetated areas or archaeological sites as a target. Therefore reflectance for each measurement can be calculated using the following equation (2):

$$\text{Reflectance} = (\text{Target Radiance} \; / \; \text{Panel Radiance}) \times \text{Calibration of the panel} \qquad (2)$$

In order to examine the use of broadband vegetation indices such as NDVI, narrow band reflectance (from the spectroradiometer) needed to be recalculated according to the spectral characteristics of a specific satellite sensor. The authors selected to simulate these data to Landsat TM /ETM+ satellite imagery based on Relative Spectral Response (RSR) filters. RSR filters describe the instrument relative sensitivity to radiance at various part of the electromagnetic spectrum (Wu et al. 2010). These spectral responses have a value of 0 to 1 and have no units since they are relative to the peak response (Fig. 7, left). Bandpass filters are used in the same way in spectroradiometers in order to transmit a certain wavelength band, and block others. The reflectance from the spectroradiometer was calculated based on the wavelength of each sensor and the RSR filter as follows:

$$\text{Rband} = \Sigma\,(\text{Ri} * \text{RSRi}) / \; \Sigma\text{RSRi} \qquad (3)$$

Where: Rband = reflectance at a range of wavelength (e.g. Band 1)
Ri = reflectance at a specific wavelength (e.g R 450 nm)
RSRi = Relative Response value at the specific wavelength

To avoid any errors due to significant changes in the prevailing atmospheric conditions, the measurements over the panel and the target are taken in a short time. In this case it is assumed that irradiance had not significant change which is true for non hazy days (Milton et al. 2009). Finally the measurements were carried out between 10:00 and 14:00 (local time) in order to minimize the impact of illumination changes on the spectral responses (Milton, 1987) at a height of 1.2 m (Fig. 7, right)

3.3 Spectral libraries

Spectral signature diagram is an easy way to plot target reflectance against wavelength, in a graphical form. Therefore ground field measurements from archaeological sites may be used in order to create an "archaeological" digital spectral signature library. Even though several remote sensing applications investigate the correlation of the spectral signature of an object,

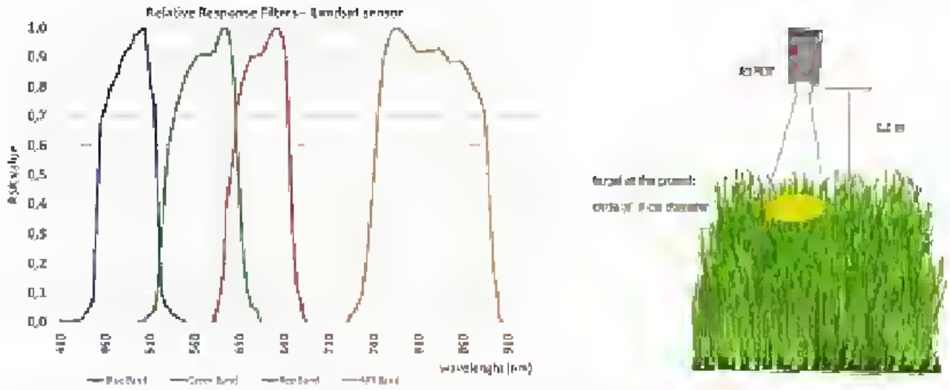


Fig. 7. Relative Response filters for Bands 1-4 of Landsat TM sensor (left) and typical diagram of the in-situ spectroradiometric measurements.

in the majority these applications the aim is exactly the opposite: the study and identification of "unknown" targets through the spectral signature. Therefore "archaeological" spectral libraries may be used for identification or correlation of different archaeological sites remotely.

Different spectral signatures from the archaeological site "Tombs of the Kings" (Agapiou et al. 2011a) and "Sikyon" archaeological sites were taken. Spectral profiles indicate that there is great potential for detecting archaeological remains in the spectral range between 550 – to 850 nm (from the green visible part of spectrum to near infrared) because of the extremely different spectral response of the archaeological material compared to sand and local marl/carbonate sandstone in the archaeological site "Tombs of the Kings"(Fig. 8). Similar results were found for "Sikyona" site also (Fig. 9).

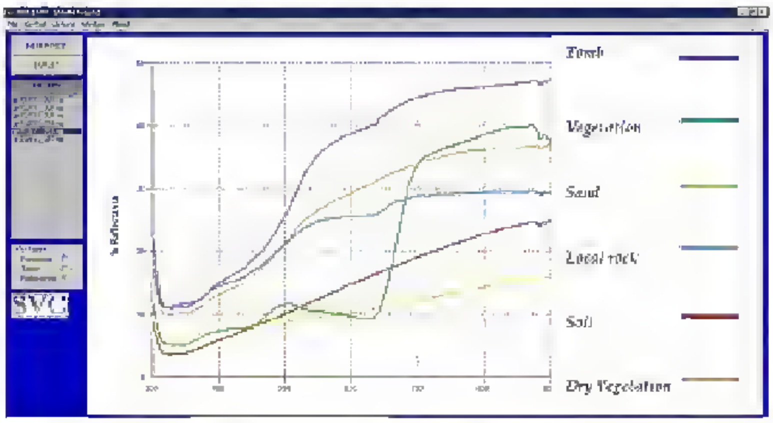


Fig. 8. Spectral signatures profiles from different targets at the archaeological site "Tombs of the Kings".

Spectral signatures libraries proved to be really efficient for any potential researcher that may use satellite imagery in order to detect archaeological relics in the area because it highlights the high correlation of spectral response of archaeological material, sand and local geological formations in the area of red visible band.

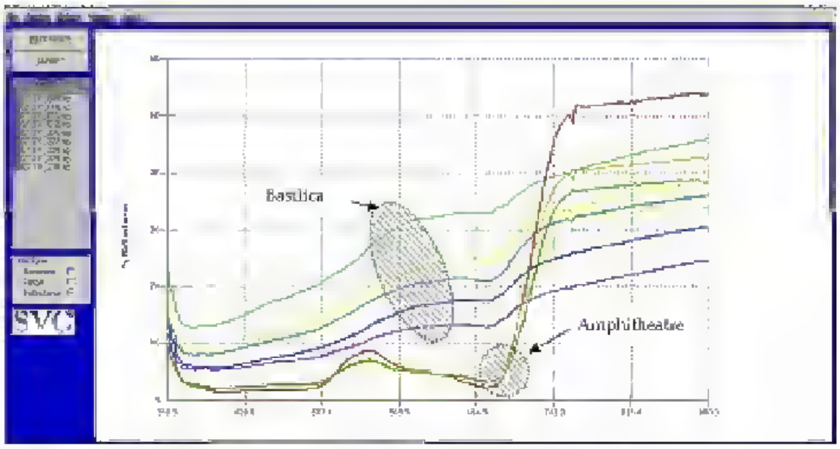


Fig. 9. Spectral signatures from the archaeological site of Sikyon.

3.4 Atmospheric correction of satellite images based on ground data

Atmospheric correction of satellite images is a necessary pre-processing step before any image analysis. Earth's surface radiation, undergoes significant interaction with the atmosphere before it reaches the satellite sensor. This interaction is stronger when the target surfaces consist of non-bright objects, such as vegetated areas examined in many archaeological studies. This problem is especially significant when using multi-temporal satellite data for monitoring purposes (Hadjimitsis et al. 2010). As Lillesand et al. (2004) argue satellite images need to be atmospherically corrected before being subjected to any post-processing techniques.

Atmospheric effects are a result of molecular scattering and absorption of the incoming radiation and influence the quality of the information extracted from remote sensing images. Such errors occurred by atmospheric effects can increase the uncertainty up to 10%, depending on the spectral channel (Che and Price, 1992). Hadjimitsis et al. (2010) have also highlighted the importance of considering atmospheric effects when several vegetation indices, such as NDVI were applied to Landsat TM/ETM+ images for agricultural applications. In their study a mean difference of 18% for the NDVI was recorded before and after the application of darkest pixel method. Therefore atmospheric correction is an important pre-processing step required in many remote sensing applications since is needed to convert the at-satellite spectral radiances of satellite imagery to their at-surface counterparts.

The modified Darkest Pixel (DP) atmospheric correction method (Hadjimitsis et al., 2004) was applied to multi-series Landsat images (Agapiou et al., 2011b). The surface radiance of the dark targets is assumed to have approximated zero surface radiance or reflectance. Instead of assuming $L_{darkest\ target}$ to be zero value, the modified DP considers the 'true' ground radiance or reflectance value over dark targets as the $L_{darkest\ target}$.

For this reason ground spectroradiometric measurements were taken in inland clear water target (Asprokremmos Dam in Paphos). The GER-1500 field spectroradiometer was equipped with a fibre optic probe was used in order to retrieve the spectral signatures from the dam. After using the RSR filters for Landsat TM/ETM+ images the spectral reflectance

after the atmospheric correction was calculated. The results have shown that satellite images were slightly improved after the removal of atmospheric effects. Indeed crop and soil marks from archaeological areas were enhanced. Photo interpretation quality was enchanced at images with low water vapour optical thickness and in general for images with water vapour optical thickness less than 0.05, the quality of the images after the atmospheric correction was improved. In the case of higher values the quality was not improved sufficiently (Agapiou, 2011a). Fig. 10 shows some typical histograms before and after the atmospheric correction. As it is shown the initial histogram of the image is stretched and therefore interpretation is improved.

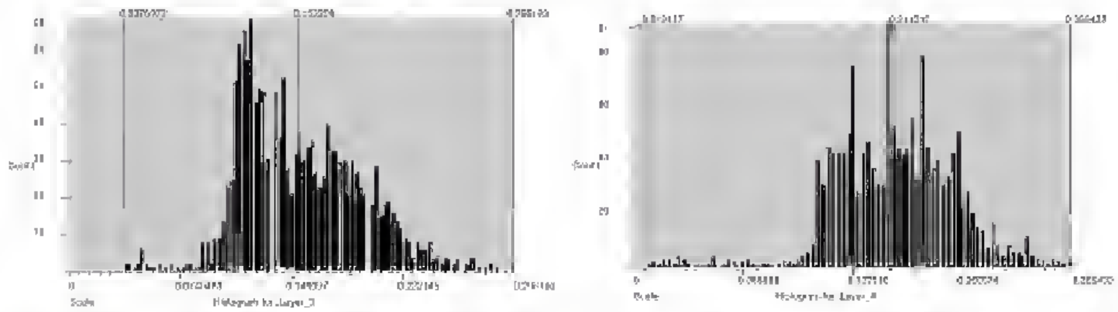


Fig. 10. Histogram for Band 3 before (left) and after (right) atmospheric correction (image: Landsat TM, 25-09-2009).

Generally the interpretation showed that in cloud-free image with low water vapour optical thickness (≈ < 0.05) atmospheric correction can increase the quality of the satellite image and therefore improve the interpretation.

3.5 Verification of buried archaeological sites

Field spectroscopy can be also used for detection of buried archaeological remains. The advantage of using ground spectroscopy against satellite remote sensing, is based on the fact that the researcher may repeatable use such methodology in contrast to the temporal resolution of satellite images (e.g. 16 days for Landsat images). Although spatial resolution is increased (few cm) the extent and scale of spectroscopy is limited compared to the area coverage of a single satellite image.

For the verification of known archaeological sites using ground spectroscopy, GER 1500 spectroradiometer was used in several vegetated archaeological sites. In this chapter results from field campaigns over Neolithic tells in Thessaly (central Greece) and buried remains in the Palaepaphos area (SW Cyprus) are presented (Agapiou et al., 2010; Agapiou and Hadjimitsis,2011 ; Agapiou et al., 2012a). In each archaeological site several sections were carried out. For the first site, along each section, more than 50 ground spectroradiometric measurements were taken while in each consecutive 5th measurement the calibration spectralon panel was used in order to minimize sun changes illuminations. At the second case study measurements were taken over known geophysical anomalies (potential subsurface monuments). To avoid differences due to variations in cultivation techniques, all measurements were carried out within the same parcel. As it shown in Fig. 11, vegetation indices such NDVI and Simple Ratio tend to give higher values at the highest peak of the tell,

similar to other flat – healthy crops of the area, while the slope of the tell gives lowest NDVI and SR values. This is due to the fact that top of the tell seems to have similar hydrological behaviour as the flat healthy region (e.g. same level of water surface run off and similar inclination ≈ 0%) in contrast to the slope of the tell. The sloping part of the tell seems to behave differently due to rainfall erosion processes. All these results denote the correlation between the morphology and the spectral response of canopy on the magoules (Agapiou et al., 2012a). Moreover ground spectral signatures at Palaepaphos area (Fig. 11) indicated a stress condition for crops over the geophysical anomaly in contrast to the rest of the measurements. This stress condition was detected from ground spectroradiometric measurements as shown in Fig. 11.

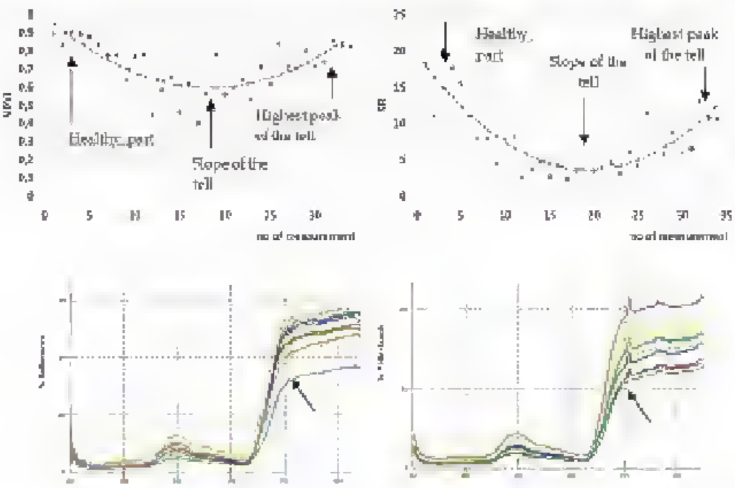


Fig. 11. NDVI (Top left) and Simple Ratio (Top right) profile over archaeological site at Thessaly. Spectral signature profiles over geophysical anomaly (indicated with arrow) at Palaepaphos (Bottom).

The results of Thessaly were able to be confirmed using Landsat TM/ETM+ images. Indeed as it was found the similar characteristics were observed and in satellite images (Fig. 12). Therefore using this experience of the spectroradiometer, where ground hyperspectral data were collected, a researcher focusing in satellite imagery can seek and search for similarly spectral characteristics as those in the spectroradiometric campaign.

3.6 Monitoring phenological cycle of crops

Monitoring the phenological cycle of crops for archaeological sites has been very limited discussed in the literature. Nevertheless as Agapiou and Hadjimitsis (2011) argue, that this approach may be used –under some assumptions- for the detection of buried archaeological remains. This methodology may be used in cases were spatial resolution of satellite imagery is very low or the cost of high multispectral satellite imagery is forbidden for an archaeological research. The basic theory of the applied method is based on the different spectral signature characteristics of 'stressed' (negative crop mark due to buried walls) and 'non-stressed' (i.e. healthy) vegetation based on the following two criteria: (a) similar soil characteristics & (b) similar climatic characteristics. The determination of spectral signatures of barley can be also verified using field spectro-radiometric measurements.

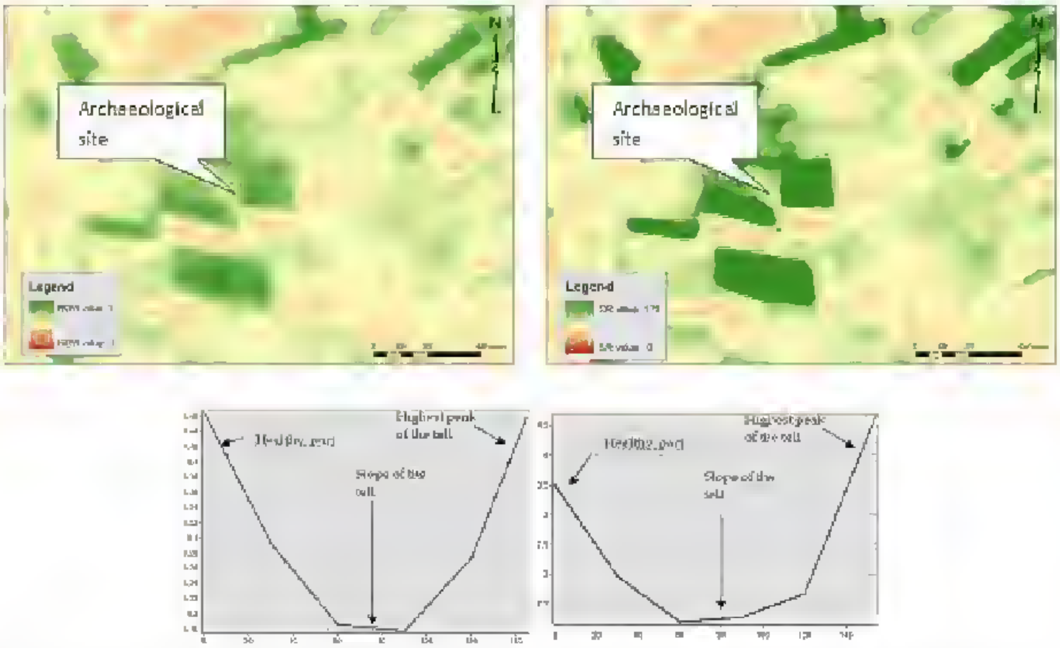
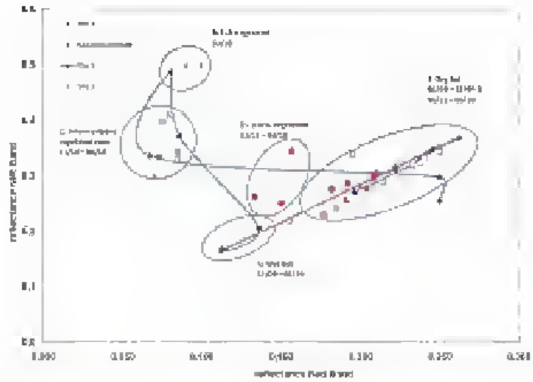


Fig. 12. NDVI (Top left) and Simple Ratio (Top Right) images over archaeological site at Thessaly using Landsat TM image. Characteristics sections of NDVI (Bottom left) and Simple Ratio (Botom right) over the tell Nikaia 6.

In their study Agapiou and Hadjimitsis (2011) and Agapiou et al. (2012b) have used fifteen Landsat TM and ETM+ images all freely available from USGS Glovis database. After applying the necessary pre-processing steps, such as geometric and radiometric corrections, the NDVI algorithm was applied in three selected case studies where barley crop was cultivated. The whole phenological cycle of barley crops was examined for a period of one year, from June 2009 until June 2010, using Landsat TM/ ETM+ images, in order to detect areas of "possible" archaeological remains indicated as spectral signatures anomalies. Site 1 was an archaeological area excavated in July 2010 by the Department of Antiquities, while sites 2 and 3 were healthy sites. Moreover site 3 was in close proximity to site 1 in order to minimize errors due to different climatic or soil characteristics.

At the same time meteorological data have not shown any significant variations over these sites (temperature, precipitation and humidity). Fig.13 shows the red and near infrared values during the phenological cycle. As it is expected in a healthy situation (similar to the Tasseled Cap algorithm, see Kauth and Thomas 1976) after the first rains the vegetation starts to grow until its reach to its highest peak (see Site 2, Fig.13). However this is not the case for stress crops as in the case of the archaeological site (site 1). A stress condition is indicated as it is shown in Fig.13 (Point D) which may be related to the presence of archaeological remains in the area. Fig.13 presents the phenological cycle of the three sites as examined by Agapiou and Hadjimitsis (2011). As indicated in 07/01/2010 an immediate drop of NDVI value was found for Site 1 (archaeological site). The low NDVI value could be explained as a result of the presence of areas of potential archaeological site, which affected the growth of the crop. The agricultural barley crop in Site 1 can be characterized as a "stressed" vegetation (negative crop mark predominantly found above walls). The excavations carried out in the area have



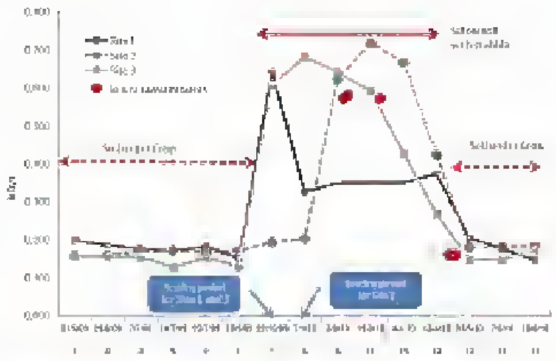


Fig. 13. Red band against NIR band during the phenological cycle of crops (Agapiou and Hadjimitsis, 2011) (left). NDVI for archaeological and non archaeological areas. In situ Spectroradiometric measurements are plotted as dots (right).

verified that this localized crop stress was due to the presence of archaeological remains (walls). Positive crop marks, due to ditches (crop vigour), were not found either in the methodology applied or in the excavated area. In the non-stress area of Site 3, crops were still growing this period indicating a peak of the NDVI value.Crops in Site 2 have not yet grown at this time. From 07/01/2010 until 31/05/2010, crops in Site 2 start to grow gradually until the harvest period. The chronological shift (X – axis) occurred in NDVI peaks for Sites 1, 3 (at 22/12/2009) and Site 2 (at 19/03/2010), as recorded from the satellite images, were due to different land management of the fields in these two areas.

4. Ground based geophysical techniques

Electrical resistivity tomography (ERT) uses various combinations of distances among equally spaced electrodes (of a specific array) in order to extract information about the lateral and vertical variations of the apparent resistivity.

Magnetic methods on the other hand are passive, measuring the magnetic properties of the soils or the magnitude of the local magnetic field of the earth as it is modified by the magnetic properties of the underlying features. The local magnetic field of the earth is modified by either the enhancement of iron oxides due to past activities or due to the burning of features, which upon cooling they keep a permanent thermoremanent magnetization, quite distinct from the current magnetic field (in intensity and direction) (Aitken, 1974 ; Sarris & Jones, 2000). Based on this property, magnetometers measure either the total magnetic field (through proton precession or cesium magnetometers) or one of its components, for detecting variations of the magnetic field (magnetic anomalies) that can be caused by anthropogenic buried agents (Nishimura, 2001). In order to account for the diurnal variations of the magnetic field and counterbalance effects resulting from geological trends, these instruments were also used in a gradient mode. Similarly, the use of fluxgate gradiometers (measuring the vertical magnetic gradient) was essential for increasing the sensitivity (although not comparable to that of the cesium or optically pumped alkali vapor magnetometers) and sampling pace of the magnetic surveys (Fig. 14). Penetration depth of the magnetic gradient surveys depends on the distance between the two vertical magnetic sensors.

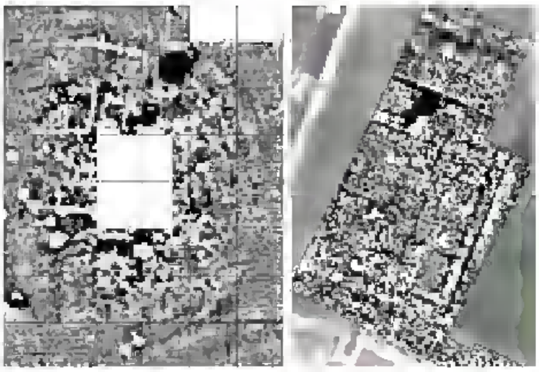
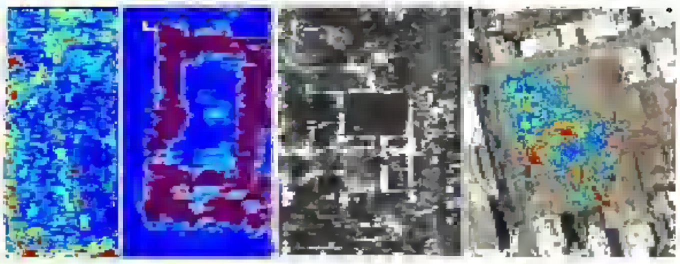


Fig. 14. Results of the usage of Geoscan FM256 and Bartington G601 fluxgate gradiometers for the mapping of the Early Copper Age (ca. 4,500-3,900 BC) settlement of Veszto-Bikeri, in the Great Hungarian Plain (left image) and the urban center of ancient Nikopolis (Epiros, NW Greece) (right image). The magnetic survey on the Hungarian Bronze Age tell revealed three circular ditches encircling the settlement, which consists of a dense cluster of structural remains (rectangular houses, pits, kilns, etc) (Sarris et al. 2004). In the case of ancient Nikopolis, a large complex building (45x70m) with a number of internal divisions appeared right at the edge of the SW corner of the Byzantine Paleochristian walls (Sarris et al., 2010).

Electromagnetic methods (EM), including the ground penetrating radar (GPR) and the soil conductivity techniques (SC), have been also employed for the prospection of archaeological sites and the reconstruction of the ancient terrains. The Slingram type of soil conductivity devices (such as Geonics EM31 or EM38) operate at low frequencies (usually at the range of 50-300kHz), make use of the electromagnetic induction and are capable of providing measurements of both soil's apparent electrical conductivity (quadrature component) and apparent magnetic susceptibility (in-phase component), with various penetration depths depending on the orientation (vertical coplanar (VCP) and horizontal coplanar (HCP) orientations), the frequency of operation and separation of the transmitter and receiver coils (Dalan, 2006; Gaffney & Gater, 2003; Cheethman, 2010). The strength of EM signals that are registered by the receiver system depends on the conductivity of the soils, the magnetic permeability and the dielectric permittivity (especially for the GPR). Operating within the range of radio frequencies, GPR systems consist of a transmitter antenna that sends a signal (~30-1000MHz) which propagates through the different strata or features (reflectors) of the subsurface and a receiver antenna that registers all the secondary reflections (with a modified amplitude) that arrive to it after a time delay which is converted to the depth. Signal attenuation and penetration depth of the GPR decreases with the increase of the frequency of the antennas and the conductivity of the soils. GPR signals are collected with high sampling rate along transects and the resulting reflection sections (radargrams) represent the variation of the amplitude of the reflected signal with depth and thus they depict an image of the stratigraphy of the subsurface. GPR parallel transects are usually combined to created 3D volumetric maps of the subsurface and through the isolation of specific time or depth slices it is possible to allocate the horizontal extent of archaeological features at different depths, which is of importance especially in cases that one wants to have information regarding the vertical extent of the features or to construct 3D models of them. In this sense, the GPR survey can be valuable in mapping different occupation strata and resolving features that are located at various depths (Fig. 15) (Conyers, 2004; Conyers & Goodman, 1997).



(a) Section of a Stoa from the ancient Agora of Feres (Velestino) in Thessaly. The (image dimensions: ExN=16x40m).
(b) Monumental structural remains SE of the Zeus temple in the archaeological site of Nemea, Peloponesse. (image dimensions: ExN=7x15m) (Papadopoulos *et al.* 2011).
(c) Architectural complex at a depth of 90-100cm below the surface located to the east of the Agora of Sikyon at NE Peloponesse (image dimensions: ExN=30x50m).
(d) The 2.5-3m GPR depth slice from the area of the hypothesized amphitheatre of Ierapetra (SE Crete). The survey was carried out in the area that was suggested through the rectification of the map of the British Vice-Admiral Thomas Spratt (1811-1888) (which was depicting the approximate location of the amphitheatre) on the satellite (Quickbird) image of the region. The deeper GPR slices in combination to ERT measurements provided evidence for the underlying relics of the amphitheatre (Sarris et al., 2011).

Fig. 15. Examples of GPR time slices obtained by Nogin Plus (Sensors & Software) GPR system using a 250MHz antenna.

Even microgravity measurements have been carried out for the detection of features that have a substantial mass density contrast with respect to their surrounding geological domain, creating a difference at the local gravitational acceleration. Measurements of earth's gravitational acceleration are carried out though the use of gravimeters that measure the acceleration of gravity within a hundredth of a mGal (1Gal=1cm/sec^2) or less. As such, the resolution of the method is dependent on the size and volume of the targets and requires tedious corrections and processing (such as drift correction, latitude correction, free air correction, Bouguer correction, etc) as measurements are influenced by the regional or even local trends. A recent review of archaeological, environmental and geological microgravity applications has been provided recently by Eppelbaum (2011).

Mainly used for landscape reconstruction, large monumental structure detection and deep prospection surveys, seismic techniques exploit acoustical waves generated either by a sledge hammer or an explosion discharge. In seismic refraction, the acoustic wave sensors (geophones) are laid along specific distances and record the refracted signals with respect to their arrival times and in this way their velocity of propagation (increasing with depth) is measured. Seismic reflection techniques require a smaller distance between the source and the geophones and through the examination of the arrival times, amplitude and shape of the reflected waves, we can conclude on the types of the subsurface interfaces (Metwaly et al, 2005 ; Scott & Markiewich, 1990).

If the above techniques are capable of providing a mean of detection and localization of architectural features within an archaeological site, magnetic susceptibility (MS) measurements and chemical analyses can contribute in providing a further tool for investigating the land use patterns at a specific area. Magnetic susceptibility provides not

only a measure of the effectiveness of the potential application of magnetic surveys (through the estimation of the normalized Le Borgne Contrast, namely the variation of the magnetic susceptibility with depth), but also an index of the past workshop activities in an area. Measurements of the magnetic susceptibility and the frequency dependent susceptibility (namely the variation of MS with the frequency of an induced magnetic field) are capable in distinguishing soils enriched in single domain magnetic particles (from the geological origin multidomain particles) which are indicative of the intensity of the occupation of a site (Clark, 1990; Mullins & Tite, 1973; Thompson & Oldfield,1986). Coupled with results of chemical properties of soils (especially those dealing with phosphate analysis or heavy metals tracing) it is possible to characterize the type of workshop activities (eg. increase of manganese content can be associated to glass workshop activities) or differentiate areas used for animal husbandry, midden deposits, foundation trenches, cultivation, cooking, etc. Even chemical stability of certain organic chemical compounds (e.g. coprastanol) may act as a biomarker of the human presence at a particular locatio (Sarris, 2008).

The choice of the technique depends mainly on a number of factors: the type of the targets, their lateral and vertical dimensions, their deposition depth and type/properties of the surrounding soils (to be able to create a significant signal, contrast or "anomaly"). Architectural features such as stone/brick structures, roads, walls, built/chamber or rock-cut tombs, can be relatively easily resolved through soil resistance or GPR surveys. Brick structures or architectural features that are either burnt or contain residues of heating/burning, kilns, workshop facilities, slag deposits, metal concentrations, and sometimes roads, walls and fortifications can be detected through magnetic and electromagnetic techniques. The use of ERT, GPR and microgravity is especially useful for the identification of vaults, caves, chamber tombs and fissures. Shallow depth surveys usually employ magnetic, soil resistance techniques and the use of GPR. In cases where deeper penetration is required GPR, ERT and seismic approaches are more appropriate (Fig. 3) (Sarris 2008, Linford 2006).

Ground based prospection techniques are not only limited to the survey of archaeological sites in an open/rural context (Fig. 16). They can also be applied within an urbanized environment, but in such a case only specific techniques can be used (such as ERT and GPR) that are influenced as less as possible by the modern interventions and structures that exist in the urban matrix. A lot of these applications do not only involve the mapping of the subsurface (eg. below asphalt roads, pavements, concrete blocks, etc), but sometimes they are oriented towards the stability or structural damage assessment of monuments or historical structures aiming towards their architectural restoration (Bertroli et al., 2011; Pettinelli et al., 2011; Utsi, 2010; Masini et al., 2010).

Currently there are two different tendencies in archaeological prospection: the integration of different geophysical techniques for maximizing the information content and the employment of multi-sensor methods for the rapid coverage of sites. In most cases, the integrated use of various techniques is employed to extract more information about an archaeological site, allowing the interpretation of various measurements that are dealing with different properties of the soil. The fusion of this information permits a more holistic approach as the data can complement each other and provide a more integral plan of the subsurface features. One the other hand, the recent development of new multi-sensor (for magnetics), multi-antennas (for GPR) or multi-electrode (for soil resistivity) motorized systems carrying DGPS allow the fast and detailed assessment of large regions, although

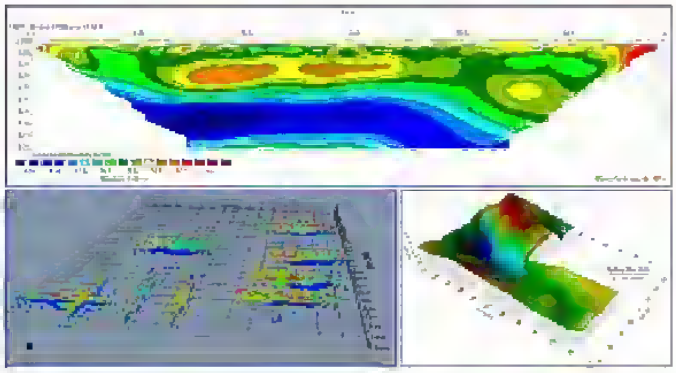


Fig. 16. Example of the application of ERT in the area of the assumed hippodrome in the archaeological site of Nemea, Peloponesse. A number of ERT transects was materialized reaching the depth of about 9m below the surface. Upon the synthesis of all the 2D resistivity inverted sections (a), it was possible to create a scatter plot of all the sections (b) and through interpolation techniques the 3D volumetric resistivity map. The isolation of the various strata of the subsurface was based on the range of their resistivity values (c). In the particular case, the iso-resistivity surfaces that resulted from the ERT transects did not identify any specific leveling of the subsurface at the west side of the archaeological site where the hippodrome was expected, suggesting that the original hypothesis of the archaeologists has to be rejected (Papadopoulos et al., 2011).

they are restricted by the surface coverage and the terrain morphology (Linford et al., 2011; Doneus et al., 2011). Although the particular systems offer increased sampling density and rates of coverage, they often suffer from positioning errors due to high measuring velocities and the introduction of noise due to the non uniform balancing of the sensors or multichannel GPR systems (Zollner et al., 2011; Verdonck & Vermeulen , 2011).

Finally, image processing techniques play a significant role in the visualization of the results of the geophysical surveys as the ultimate goal is to provide images that they depict the underlying features at their exact location and horizontal/vertical extent in a way that can approach the results of an after-the-excavation plan. This objective can be achieved through the use of a number of filtering/convolution processes, the employment of synthetic models or inversion algorithms, or other image processing functions (Papadopoulos & Sarris, 2011; Sarris, 2008; Loke & Barker, 1996; Scott & Markiewich, 1990). In cases that multiple datasets are available for the same region, composites can be made using visualization techniques similar to those used in satellite remote sensing (Böniger & Tronicke, 2010). Even more impressive visualization can be created through the fusion of geophysical data with satellite remote sensing or aero-photogrammetric data and lidar or terrestrial 3D laser scanning (Bem et al., 2011). Indeed, the continuous improvement of high resolution satellite remote sensing sensors has made possible their simultaneous utilization with conventional geophysical data affecting their resolution and potential in the detection and mapping of underground features (Crespi et al., 2011).

5. Conclusions

The various approaches applied on different satellite images for the detection of Neolithic settlements in Thessaly illustrated the benefits that satellite remote sensing can provide in

archaeological investigation. It was proven that an integration of images from different satellite sensors can contribute to a faster and more accurate and qualitative detection of archaeological sites. In addition, the GIS spatial analysis and DEM processing contributed substantially to the detection and monitoring of settlements and modeling of Neolithic habitation partners in Thessaly.

Moreover, it was proved that spectroradiometric measurements can be used as an alternative approach in order to identify buried archaeological remains, since they can provide accurate spectral signatures for a wide spectral region. Anomalies of the crop spectral signatures due to buried archaeological remains can be recorded in detail and contribute to the construction of a predictive archaeological model in the future. However, the real benefit of this instrument is when it is used in conjunction with satellite images. Moreover the spectroradiometric measurements highlight the high correlation of spectral response of archaeological material, sand and local geological formations in the area of red visible band. Finally it was proved that the monitoring of the phenological cycle of crops can be used for the detection of buried archaeological sites.

At the end geophysical survey, ground and space remote sensing methods have been gradually adopted in archaeological research in an effort to capture the residues of the past anthropogenic activity underlying below the current surface of the ground and to provide a more synthetic and holistic image of the archaeological landscapes. Magnetic and resistivity techniques, electromagnetic, gravity and seismic methods, measurements of the chemical and magnetic properties of the ground, have been all mobilized to produce an accurate picture of the underlying monuments, contributing to a variety of applications in both urban and rural environmental settings. In this way all these different methodologies Have been applied to various areas of potential archaeological interest throughout Europe. The tuning of the methods and the corresponding instrumentation, together with the development of specific processing algorithms, are necessary in order to enhance the shallow depth signals that are registered within the increased noise levels of upper horizons of the soil. In this way, shallow depth prospection techniques have been used to map architectural relics, to guide excavations, and to identify craft, workshop, agricultural or animal husbandry activities.

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